

A Business Process Framework and Operations Map for Maritime Autonomous and Unmanned Shipping: MAUSOM

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Abstract. Maritime autonomous and unmanned shipping have considerable potential for cost-effective and safe cargo or passenger transport and other maritime operations. Such a manner of shipping will introduce operations chains with new roles and responsibilities. Widescale adoption requires an agreed upon overarching business process framework and operations map. Therefore, this paper introduces MAUSOM: the Maritime Autonomous and Unmanned Shipping Operations Map. Within the maritime industry and research community MAUSOM can be used as a shared blueprint for (re-)designing the operations processes and for defining the supporting functional capabilities. Furthermore, it structures the task allocation process to identify those tasks that can and those that (currently) cannot be allocated to software modules. Furthermore, it enables the definition of the data models needed for the overall system design. The MAUSOM methodology is based on the similar and successful enhanced Telecom Operations Map (eTOM) framework approach from the telecommunication sector [11]. MAUSOM uses Hierarchical Task Analysis (HTA), which has a long tradition as human factors' functional decomposition method for engineering maritime operations. This paper describes MAUSOM, the benefits of its standardization and adoption for various stakeholders in the maritime shipping operations chain and addresses its development and deployment governance aspects.

1. Introduction

Maritime autonomous and unmanned shipping have considerable potential for cargo or passenger transport and for performing other maritime operations in a cost-effective and safe way. It will impact the manner in which the maritime shipping business operates, introduce new roles and responsibilities in shipping operations and transforms the supporting digital information chains. Not only does this apply to the primary navigation and nautical processes, it also applies to the embedding within the overarching logistic cargo supply chain and passenger management deployment processes.

Wide-scale adoption of maritime autonomous and unmanned shipping can be enormously facilitated and stimulated with an aligned, accepted and preferably agreed upon (standardized) overarching business process framework and operations map in which these overarching deployment processes are taken as a basis. The main merits include:

- it provides a validated, complete and shared model for identifying all functions and tasks for autonomous and unmanned shipping,
- it guides the task (re-)allocation process to either autonomous systems or to human operators,
- it enables interoperability between (sub-)systems and thereby reduces the costs of integration,
- it forms the basis for a structured information model supporting system interconnectivity, and
- it provides a blueprint for operational process and runtime use case (re-)design.

The maritime industry and research community have recognized the need for an agreed-upon business process framework and operations map. Various initiatives in that direction have been taken.

The EU research project MUNIN (Maritime Unmanned Navigation through Intelligence in Networks) has provided a functional decomposition for unmanned / autonomous and unmanned shipping [14], consisting of 10 main function groups, each containing a set of sub-functions. In total, a set of 40 sub-functions has been identified.

The Bureau Veritas classification society has provided guidelines [5], including a set of six autonomous systems with their functional capabilities for the operations of autonomous ships: the Navigation System, the Communication Network and System, the Machinery System, the Cargo Management System, the Passenger Management System, and the Shore Control Centre.

In addition to these initiatives, regarding the methods used, functional decomposition has a long tradition as a human factors' method for engineering and design. Particular the method of Hierarchical Task Analysis (HTA) is used to produce an exhaustive description of tasks in a hierarchical structure of goals, sub-goals, operations and plans [18]. In HTA, tasks are broken down into progressively smaller units. Operations are the actions performed by people interacting with a system or by the system itself, and plans explain the conditions necessary for these operations. Operations describe the smallest individual task steps in the HTA, i.e. those which cannot be broken down into further operations. Task description is a necessary precursor for other analysis techniques, including task allocation. As an example, a functional description of Bulk Carrier operations can be found in [3]. Moreover, the HTA principle has also been applied in the Crew Design Tool (CDT) [6]. Developed to be applied in the early design phase of a vessel, the tool captures and shares knowledge of ambition levels, personnel, automation, and concepts of operations, using reusable, formally (digitally) specified modules and computes ship configurations that are assembled from these modules.

Despite the mentioned initiatives and usage of modelling methods, a sound and agreed upon process framework and operations map embedded in the overarching deployment processes is still lacking. The goal of this paper is to address this lacuna by introducing the (methodologically embedding of the) Maritime Autonomous and Unmanned Shipping Operations Map (MAUSOM) and to provide a functional decomposition of the operations processes for MAUSOM into functional capabilities at various levels of detail, with a focus on the safety of navigation and nautical processes.

This paper is structured as follows: The new emerging ecosystem for maritime autonomous and unmanned shipping supporting as part of the overarching deployment processes is outlined in section 2. Section 3 introduces the MAUSOM business process framework, its goal, benefits and structure. Section 4 elaborates the MAUSOM using a functional decomposition of the operations processes at various levels of detail. Section 5 discusses the applicability and relevance of the MAUSOM for various stakeholders in the ecosystem, followed by section 6 addressing the governance of its development and deployment to enable the MAUSOM to be successful in achieving its potential and wide-scale adoption. Finally, section 7 provides the conclusions and future work.

2. An emerging new ecosystem for maritime autonomous and unmanned shipping

The evolution towards maritime autonomous and unmanned shipping requires (re-) consideration of the way the maritime shipping business operates. As cited from [1] p79:

'Autonomous and unmanned shipping will lead to a new kind of role set and division of work between actors in the shipping sector. Some may be fulfilled by traditional actors and some by new entrants.'

These new roles and responsibilities go hand-in-hand with a digital transformation of the supporting information chains. Tasks have to be reconsidered and reallocated from human based execution to computer-based execution. Therefore, the following paragraphs in this section subsequently address the various levels of autonomy to be distinguished and the embedding thereof in the overarching deployment processes.

2.1. *The evolutionary perspective: levels of autonomy and operational modes*

The evolution path towards autonomous and unmanned shipping will be a gradual one. In its evolution path towards full-autonomy, various intermediate levels of autonomy will be traversed. Therefore, this paragraph addresses the levels of autonomy that may be distinguished.

The concept of autonomy and the concept of automation have been used interchangeably in literature [2]. Despite the fact that automation and autonomy are related in terms of make-up of a system (mechanized or not), they are not equivalent constructs. *Automation* is physical technology (mechanized or computerized) viable for application in a defined environment. *Autonomy* is a state of being for a system (mechanical or biological) implying robustness to environment, independence in action or function, and self-determination of goals and resource allocation. Or to put it in another way, autonomy can be a desirable design goal for automated systems [13].

A literature review on the levels of automation (LOA) during the years shows a rich variation in number of levels and meaning [19]. The historical first LOA description including 10 levels has been described in [17], in which the principle motivation for describing the LOA levels to clarify that automation is not an either-or [16]. This also holds for autonomous shipping. It means that it is conceivable that different voyage phases are being performed on different levels of autonomy by varying the (external) level of human control [14]. This requires adaptive function/task allocation scenarios and effective coordinated human-system performance [4].

Currently, the IMO’s MSC 99 initiative [10] analyses and assesses various definitions for the levels and concepts of autonomy. For instance, Figure 1 provides the definitions for the various Levels of Autonomy for maritime autonomous shipping from Bureau Veritas from lowest level till highest [5].

Ship category	Level of autonomy	Manned	Method of control	Authority to make decisions	Actions initiated by
Conventional	0 Human operated	Yes	Automated or manual operations are under human control	Human	Human
Smart	1 Human directed	Yes/No	Decision support Human makes decisions and actions	Human	Human
Autonomous	2 Human delegated	Yes/No	Human must confirm decisions	Human	System
	3 Human supervised	Yes/No	System is not expecting confirmation Human is always informed of the decisions and actions	Software	System
	4 Fully autonomous	No	System is not expecting confirmation Human is informed only in case of emergency	Software	System

Figure 1. The Burau Veritas levels of Autonomy [5]

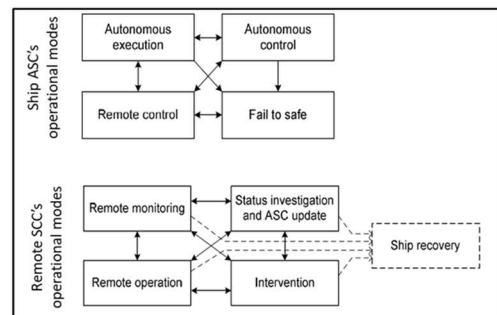


Figure 2. Ship ASC’s (u) and remote SCC’s (l) operational modes [15]

A goal of MAUSOM is to provide a framework that enables a shared understanding of the sub-processes which can be allocated to relevant software modules and understanding the (facilitating) functions that need to be allocated to human actors. In the transition towards higher levels of autonomy for autonomous and unmanned shipping, a risk-based approach based on contingency management with fall back operational modes is adopted, in which an autonomous or unmanned ship can be monitored and controlled by means of a Shore Control Centre (SSC). As such, the EU MUNIN project [15] has defined various operational modes. During its autonomous passage, an onboard Autonomous Ship Controller (ASC) system will have control over the ship in cooperation with the manned SCC that will have the possibility to remotely control the ship, if necessary. The ASC and SSC can operate in different modes as illustrated in Figure 2. As cited from [15]:

'The ASC will mainly operate in an Autonomous Execution mode where it will follow programmed track and speed instructions and will monitor its environment and ship state by its sensors. Minor problems that fall within a predefined envelope of freedom can be solved by the ASC in Autonomous Control mode. ... The SCC can at any time take over control and run the ship in Remote Control mode, completely overriding the ASC. In addition, the ASC will have one or more programmed Fail-to-Safe modes that will be activated if the SCC for some reason cannot take full remote control in a critical situation.

2.2. Autonomous and unmanned navigation within overarching ecosystem and deployment processes

For developing the shipping digital environment within the overarching deployment processes, the Digital Inland Waterway Area (DINA) initiative [7], (commissioned by the EC DG Move Digital Transport and Logistics Forum has developed a high-level framework of the (future) information stakeholders for digitization of inland waterways, with focus on cargo management in the logistics supply chains. Its approach and results can be reused and extended for embedding the case of maritime autonomous and unmanned shipping in a broader logistics supply chain perspective. Figure 3 depicts the resulting new role and responsibility model supporting autonomous and unmanned navigation.

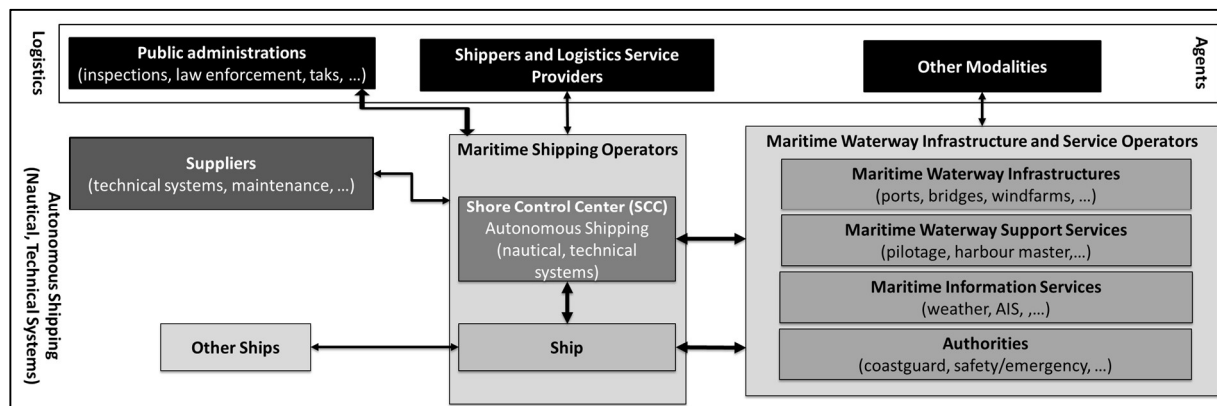


Figure 3. The operational role model for autonomous and unmanned shipping embedded within the overarching logistics deployment processes.

The figure illustrates a ‘centralized’ variant with a pivotal coordinating role of the ship control centre (SCC) in the information sharing processes between the various roles. For the operational processes as required by maritime autonomous and unmanned shipping, the introduction of the SCC forms an essential step in the evolutionary roadmap towards truly autonomous maritime shipping. Multiple ships may be remotely monitored and controlled from a single SCC. The SCC also plays a pivotal role in the overarching deployment processes, e.g. for the Business-to-Business logistics information sharing processes.

3. The Maritime Autonomous and Unmanned Shipping Operations Map (MAUSOM)

The advent of autonomous and unmanned shipping and the digital sharing of information and data will require a tight coupling of sub-processes and computer systems with different roles, and agencies in the maritime ecosystem. The complexity of the interaction and coordination will increase compared to the current loosely coupled procedures. To handle the increasing complexity of information sharing, a well-structured and optimized IT architecture is needed, based on an operations map to support the operational role model for autonomous and unmanned shipping embedded within the overarching deployment processes and elaborated into a decomposition of its main functional capabilities.

The Maritime Autonomous and Unmanned Shipping Operations Map (MAUSOM) is a reference business process framework providing such an operations map to support the operational role model. The MAUSOM structures and categorizes the operations processes for autonomous and unmanned

shipping. It provides a basis for their further decomposition into specific functional capabilities as well as the required software support systems and data models.

3.1. The business process framework methodology: an operations map

The approach for defining MAUSOM as a reference business process framework for autonomous and unmanned shipping is based on the similar approach previously successfully taken by the telecommunication industry to categorize the processes that a telecommunication service provider requires to implement and to standardize both their operations and business support systems (OSS / BSS). Its business process framework is referred to as the enhanced Telecom Operations Map (eTOM) [20]. The eTOM framework is the result of an industry wide consensus on the processes, globally harmonised and standardized through collaboration of telecommunications service providers.

For the telecommunications sector, eTOM has served as basis for a functional decomposition and for identifying and defining the information elements necessary for the execution of the telecommunication OSS/BSS processes. The result of this latter effort has meanwhile spawned its own telecommunications Shared Information and Data Model (SID). ETOM has been standardized by the Tele Management Forum (TMF) [11]. The major benefits for the telecommunication industry are:

- it provides an agreed upon and standardized structure, categorization and technology for the business and operations processes and their building blocks (capabilities),
- it provides guidance to the definition of end-to-end process flows, enabling effectivity and cost-efficiency through reuse of existing capabilities and systems with opportunities for cost and performance improvement, and for re-use of existing processes and system, and
- it enables the usage of ‘off-the-shelf’ solutions for specific capabilities and systems that can readily be integrated, with a better performance and at lower cost than custom-built solutions.

Similarly, the MAUSOM may serve as reference business process framework to categorize, identify and define the business and operational processes for autonomous and unmanned shipping, for their functional decomposition, and for identifying and defining the information and data models for autonomous and unmanned shipping. The MAUSOM is defined as much as possible as ‘generic’ operations map in an organization-, technology-, and service-independent manner. It will be described in the following sections.

3.2. MAUSOM: The basic structure

The MAUSOM reference business process framework for autonomous and unmanned shipping addresses the autonomous and unmanned shipping activities from the perspective of the autonomous ship operator, e.g. being the ship owner or a third-party operator. The basic structure of the MAUSOM Level 0 defines the main high level process areas, referred to as ‘Business Activities’. It distinguishes the operations, strategic and management processes, as depicted in Figure 4:

- *Strategy, Infrastructure, and Services*, including the strategy, planning and life-cycle management processes for defining the services and functions to be supported and its required infrastructure (both on ship and on shore).
- *Operations*, including the daily processes and activities for operating (a fleet of) autonomous and unmanned ships.
- *Enterprise Management*, including the enterprise support processes. These ‘generic’ processes cover functions such as Human Resource Management, Financial and Asset Management and Knowledge and Research Management.

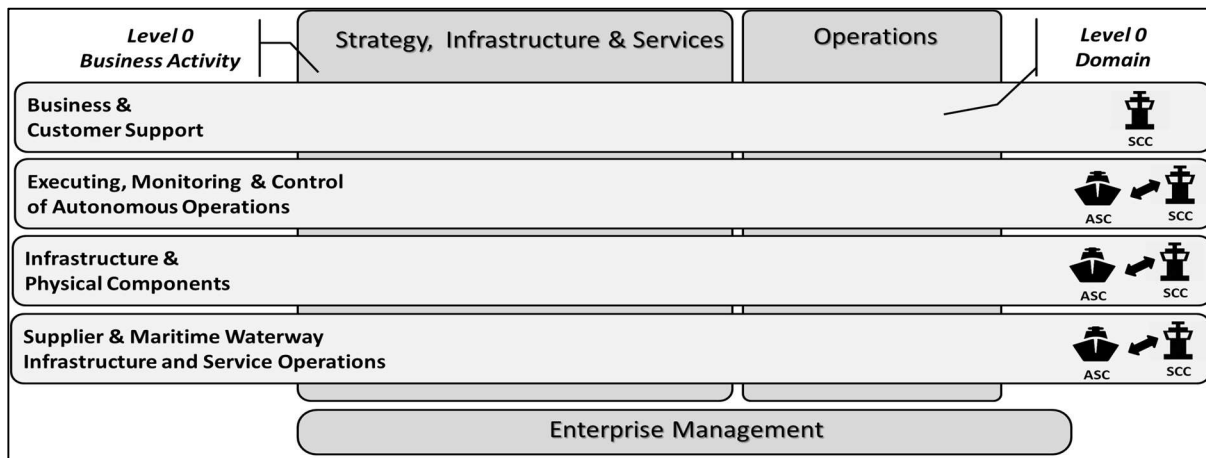


Figure 4. The MAUSOM basic structure: Level 0 Business Activities and Domains.

As Figure 4 shows, the basic MAUSOM Level 0 also includes horizontal layers, called domains, containing functional groups that span horizontally across the maritime shipping operator internal organization, i.e. the domains are related to processes within the light green box central in Figure 3. The MAUSOM distinguishes four domains:

- *Business and Customer Support*: High-level view of the embedding of the maritime shipping operator autonomous shipping activities within an overarching business or customer deployment processes.
- *Executing, Monitoring & Control Autonomous Operations*: The execution, monitoring and control of regular autonomous shipping processes of both the ship/ASC and the SCC.
- *Infrastructure & Physical Components*: Managing, maintenance and monitoring of the technical systems implementing the autonomous execution of functions.
- *Suppliers & Maritime Waterway Infrastructure and Service Operators*: Providing products and services to the maritime shipping operator for the operations and support of autonomous shipping.

In addition, Figure 4 illustrates that the MAUSOM domains are in general implemented and operated in (distributed) collaboration over the ship and the SCC. Which part of the functionality is executed on board of the ship and which part is executed within the SCC or as a human-machine collaboration may be dependent on the active ship's ASC's and SCC's operational modes (e.g. autonomous, shared control, remote control or fail-safe), as described in section 2.1. As such, it is noted that the MAUSOM structure and levels are not directly associated to specific levels of autonomy. Moreover, MAUSOM is applicable irrespective of the autonomy level aimed at. As indicated in the introduction however, it may be used to guide the task (re-)allocation process to either autonomous systems or to human operators.

The way the MAUSOM differs from the eTOM is that the latter provides a process and operations map of a new and fully digital distributed system, whereas MAUSOM will be a process and operations map of an existing maritime system that can be described as a social-technical system, i.e. a system that consists of humans, digital technology and procedures. As explained, the design objective is to maximize the role of digital technology over that of the human actor.

3.3. MAUSOM: The levels of description

The MAUSOM Level 0 process areas for Strategy, Infrastructure, and Services and for Enterprise Management are generically applicable for (larger) organizations, and not specific for maritime shipping operators of autonomous and unmanned ships. Hence, the remainder of this paper will only focus and elaborate on the MAUSOM Level 0 process area for Operations (for a description of the MAUSOM

Level 0 Strategy, Infrastructure & Services and for Enterprise Management process areas, the reader is referred to the corresponding eTOM process areas [11].

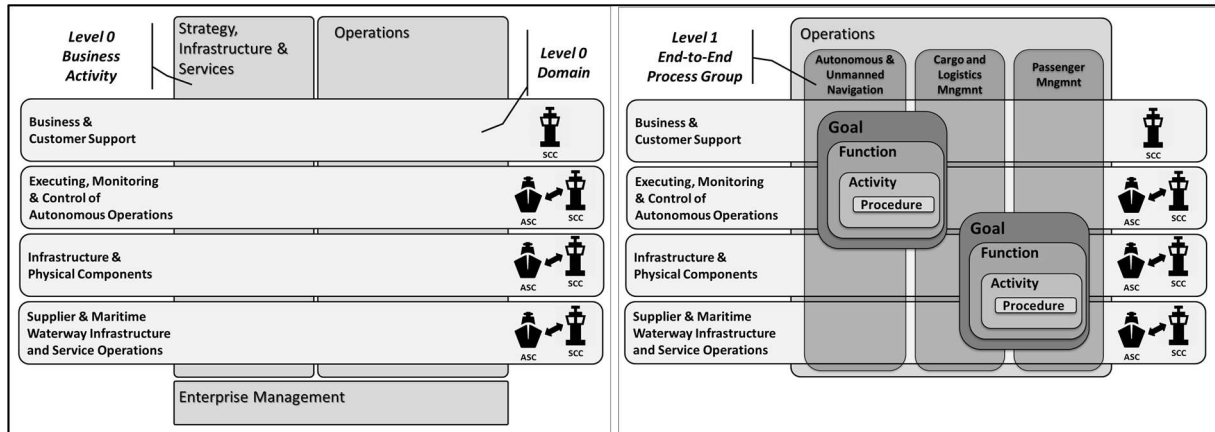


Figure 5. The basic MAUSOM Level 0 structure (l) and lower levels of detail (r).

In the right side of Figure 5 the Level 0 process area for Operations is further decomposed into Level 1 containing three so-called end-to-end process categories which are required to support the autonomous and unmanned shipping process and manage the business to customer overarching deployment processes as described in section 2. As such, the MAUSOM Level 1 distinguishes three business application sectors as end-to-end process categories for which autonomous and unmanned shipping may be deployed and that can (to a large degree) may operate independently:

- the *Autonomous & Unmanned Navigation* end-to-end process, reflecting the maritime shipping operator's internal business policy to operate their ship autonomously or unmanned.
- the *Cargo and Logistics Management* end-to-end process, reflecting the embedding of autonomous and unmanned shipping processes within the overarching logistics (cargo) supply chain processes.
- the *Passenger Services Management* end-to-end process, reflecting the embedding of autonomous and unmanned shipping processes within the overarching passenger traffic/transport services (e.g. ferries, crew transport to windmills and offshore platforms).

It is to be noted that the end-to-end process categories applicable to a specific autonomous or unmanned ship is closely related to the function of the ship, e.g. as container ship, passenger ship, tug or other. As such, other end-to-end process categories can be added to the MAUSOM framework.

Figure 5 also shows on the right that the MAUSOM Level 1, being the second highest abstraction layer, can be further decomposed into subsequent levels of lower abstraction but with higher levels of detail which is in line with the hierarchical task decomposition method described in the introduction. However, within the MAUSOM the labels for the levels are a combination of HTA and CDT labelling. The following MAUSOM decomposition levels are distinguished:

- Level 2: describes the essential objectives within the end-to-end processes. An objective is something that can only be reached through an operational process, and hence it is something that has to be performed. In MAUSOM, these essential objectives are referred to as *Goals*.
- Level 3: describes the more fine-grained functions as associated with more detailed business process flows. In MAUSOM, these are referred to as *Functions*.
- Level 4: describes the actions that need to be executed and which cannot be broken down in to further activities. In MAUSOM, these are referred to as *Activities*.

- Level 5: describes the work procedures. Only one work procedure is sufficient to realize an activity, but more can be specified dealing with different conditions in which the activity is executed. In MAUSOM, these are referred to as *Procedures*.

All activities which are under a goal in the tree must be performed to realize the goal. Only one (work) procedure (level 5) is sufficient to realize an activity. In this way, we can model and further implement different operational concepts that accomplish the same purpose. For instance, by specifying different (work) procedures for the same activity with full or less automation, or with a different staffing. If in any case the number of levels is not sufficient to get to the activity and procedure level, then the abstraction level described at level 2 is too high and should be broken down further.

Using these various MAUSOM levels of task decomposition, the MAUSOM may be used as a baseline and shared system description to be used for engineering and design. For engineering purpose, it can be used to analyse existing organizational processes to discover gaps, optimize procedures, and eliminating duplicate functions and tasks. The design purpose is to develop new organizational processes for autonomous and unmanned shipping. It allows, specifying different work procedures for the same activity with full or less automation, including requirements, inputs and outputs on the technical modules, or with a different staffing.

4. MAUSOM elaboration for autonomous navigation

A functional decomposition of the operational deployment processes for autonomous and unmanned shipping forms the basis for elaborating the MAUSOM operations framework into more detailed levels of required capabilities. This section describes this functional decomposition and presents the resulting MAUSOM Levels 2 and 3 with more detailed capabilities. The focus will be on the capabilities required to support the autonomous navigation process.

Extending on the input of the Bureau Veritas guidelines [5], the EU MUNIN project [14][15] and the functional description of Bulk Carrier operations [3], a functional decomposition with a focus on Autonomous Navigation is being proposed. It serves as an elaborated example, since part of the MAUSOM added value is an agreed-upon standard upon classification and naming. As goal definition and labelling are subjective, it is necessary to elaborate and agree on it within an international working group. Table 1 shows the MAUSOM Level 2 Goals and Level 3 Functions decomposition example, currently distinguishing and describing twelve goals. Figure 6, depicts how the MAUSOM Level 2 Goals as described in table 1 can be mapped onto the MAUSOM Level 1 End-to-end process categories.

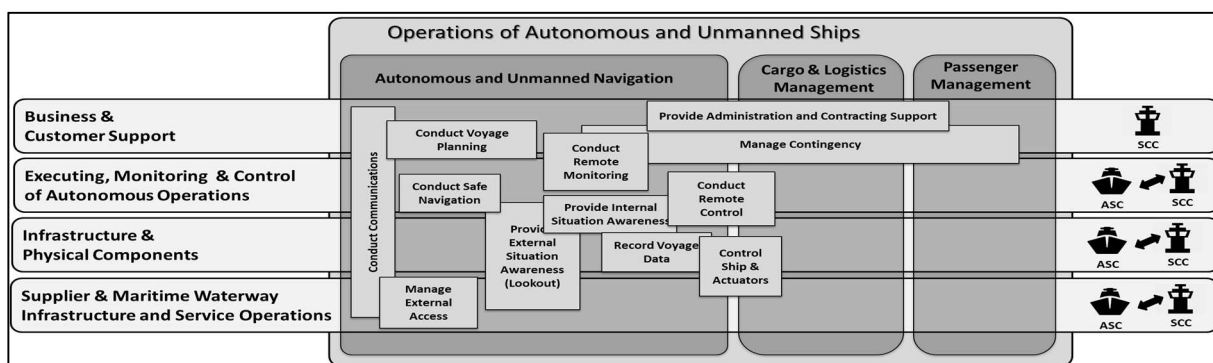


Figure 6. MAUSOM Level 2 Goals mapped upon Level 1 End-to-End Process Categories.

The Level 2 Goals are mainly situated in the Monitoring & Control Autonomous Operations and the Infrastructure & Physical Components domains because in this paper we focus on autonomous and unmanned navigation goals. As a consequence, the Business and Customer Support is (still) scarcely populated. This will increase when the scope will be broadened to include the business and customer processes.

Table 1. Functional decomposition Level 2 Goals and Level 3 Functions.

MAUSOM Level 2 Goals	MAUSOM Level 3 Functions
Conduct safe navigation: Plan and direct the course of a ship both under regular conditions and for special manoeuvres (e.g. docking or potential collision).	<ul style="list-style-type: none"> • Plan path • Keep track • Avoid collision
Provide external situation awareness: Generate a complete (current and predicted) external maritime picture of the navigational environment to support the navigation process, including tracking of ships and objects.	<ul style="list-style-type: none"> • Perceive extern. situation (Radar, AIS, Video, ...) • Build and predict maritime picture • Receive audio comms (e.g. voice, horn)
Record voyage data: Acquire, record and report of operational process data and the ship's technical systems.	<ul style="list-style-type: none"> • Record navigation and nautical data • Record sensor and system data
Provide administration and contracting support: Acquire, record and report of business-oriented process information, e.g. authority reporting, logbook,	<ul style="list-style-type: none"> • Report to authorities reporting • Log voyage • Administrate cargo/passenger operations
Conduct voyage planning: Define, update and describe (by a shore-based operator) of the vessel voyage from start to finish (berth-to-berth).	<ul style="list-style-type: none"> • Select ship • Define itineraries • Plan route & waypoints
Conduct remote monitoring: Remotely monitor and control the business and operational processes.	<ul style="list-style-type: none"> • Monitor ship route • Monitor vessel voyage • Monitor cargo/passenger operations
Conduct remote control: Remotely monitor and control the business and operational processes.	<ul style="list-style-type: none"> • Control ship • Control ship-to-ship operations
Control ship and actuators: Maintain and operate the ship (the hull, construction,...), its technical systems (the machinery, propulsion, rudder, thrusters, ...) and its ICT processing systems (the IT and communication infrastructure).	<ul style="list-style-type: none"> • Monitor (condition of) ship, technical systems, and ICT-systems • Detect/manage contingency constraints • Interact with ships and VTS in proximity
Provide internal situation awareness: Monitor, report and predict the internal ship technical status, and assess their impact on the ships sailing, manoeuvrability and contingency capabilities.	<ul style="list-style-type: none"> • Detect failures and alarms • Determine buoyancy and stability • Estimate maneuverability
Conduct communications: Manage the communications of the ship with the external environment (SCC, other ships, authorities, ...), incl. the connectivity links and prioritization of information flows under varying operational conditions.	<ul style="list-style-type: none"> • Manage internal communication • Manage external communication • Prioritize information flows
Manage contingency: Manage the robustness of the physical environment (personal, ship, environment), the ICT-systems and cyber resilience to anticipate, withstand and recover from both unanticipated events (anomalies) and from malicious (physical and cyber) threats and attacks, including y	<ul style="list-style-type: none"> • Monitor health of technical systems • Provide recovery procedures • Monitor ship, personal and environmental safety • Manage cyber security • Manage transitions of operational modes
Manage external access: Hand-over of autonomous and unmanned shipping monitoring and control to third parties for special activities, e.g. (un)docking and (un)mooring, tugs, remote piloting, helicopter approach, ...	<ul style="list-style-type: none"> • Provide Rendezvous Control Unit (RCU) services: pilot, tug, emergency, ... • Maintain Maritime Service Portfolio (MSP): harbour, VTS-control, ...

The MAUSOM Level 2 Goals as enumerated in the table (and their Level 3 elaboration into functions) can be mapped on the SCC and ASC implementation environment as depicted in Fig. 7.

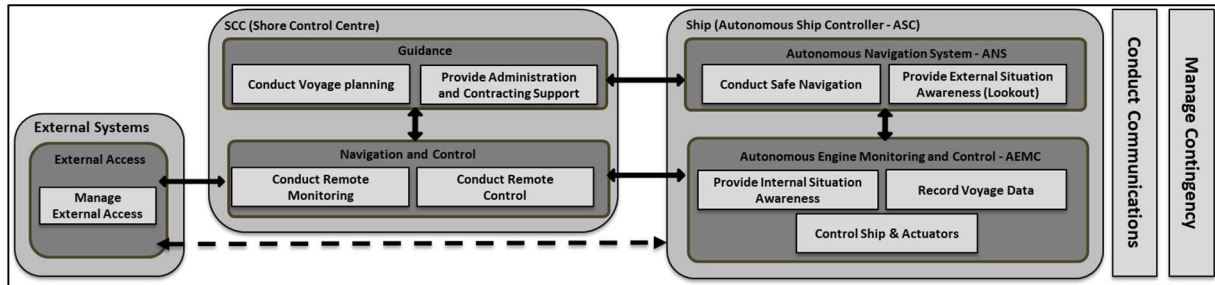


Figure 7. Relations between MAUSOM Level 2 Goals and infrastructure components.

The mapping illustrates that MAUSOM Level 2 Goals can be attributed to individual parts of the implementation environment, i.e. either to the ship, the SCC or to systems requiring external access. This (strict) separation is essential for interoperability. Through standardisation of its interconnectivity artefacts, it enables the MAUSOM Level 2 Goals to be provided by independent organizations, e.g. allowing autonomous or unmanned ships to be controlled by various SCC's on its voyage.

5. Relevance and applicability for stakeholders

For the various stakeholders in the operational role model for autonomous and unmanned shipping as described in section 2, the applicability and relevance of the MAUSOM differs.

For shipping companies, it is expected that the operations of the autonomous ships will get ever more intertwined with the shipping company's overarching business or customer deployment processes, e.g. in logistics or in passenger/personnel transport. MAUSOM provides a common understanding and blueprint for process chain development and defining interactions and general working agreements between modules and partners.

For system integrators, solution providers and ship builders, interoperability and minimizing the effort of integration of various (sub-)systems are important features. As such, the MAUSOM provides an agreed-upon (standardized) and complete decomposition of autonomous and unmanned shipping processes into a set of separate and disjunct capabilities. Moreover, it forms the basis for determining a (structured and standardized) information model for sharing and exchanging data between the systems and provides the basis for the IT process and runtime use cases design. The MAUSOM also outlines the boundaries (including requirements, inputs and outputs) on the technical modules to be developed by the solution providers, in alignment with their customers' needs. In an overall risk mitigation approach, especially for the contingency planning component in the MAUSOM, it is important that these technical modules provide descriptive information on the trustworthiness of the task they perform, e.g. for trustworthiness, data quality and reliability of Situation Awareness data and Collision Avoidance projections. Similarly, system health monitoring is a key component for contingency planning.

For classification organizations it is important to be able to identify safety critical processes and systems to be able to assess the quality of the supporting health monitoring and safety surveillance processes. This also includes the operational modus management and control processes, and the Shore Control Centre design and operations processes (including staffing, training and backup/fall-back). This requires a completely new way of assessing the safety for the autonomous ship with its operational environment, including the SCC, being an integral part of the MAUSOM. Currently, the EU H2020 project ENABLE-S3 [8] is addressing new approaches for validation and testing, including the domain of autonomous maritime shipping.

6. Discussion MAUSOM governance of development and deployment

The MAUSOM as introduced in this paper has the potential to provide major benefits for the advancement of autonomous and unmanned shipping. Nevertheless, the success of the MAUSOM strongly depends on adequate governance of both its development and deployment.

The governance of development requires a minimal rule set for the MAUSOM, its functional decomposition and the implementation of its capabilities by means of software modules. To achieve its potential benefits, the main premises for the governance of the development of the MAUSOM include:

- a) openness to additional ships and users to allow additional maritime autonomous or unmanned ships to be added,
- b) openness to service providers to provide their services, e.g. on VTS and eNavigation, and
- c) openness to solution providers to meet the necessary requirements to provide components under competitive conditions.

In an open ecosystem, a multitude of independent stakeholders provide and manage their own services and components. Nevertheless, seamless interoperability is required in jointly realizing the overarching autonomous and unmanned shipping operational environment as described in MAUSOM. Hence, all stakeholders jointly have to adhere to an agreed-upon architecture, supported by well-defined and standardized interfaces between the components. This will avoid monolithic (re-)implementations and prevent lock-in. Moreover, standardization will enable low barriers for various stakeholders to participate at minimal cost of integration. Hence, the focus of standardization must be on interoperability and accessibility, both on interfacing between the roles and between the functional components.

Open standards are a key enabler for developing and evolving the MAUSOM. The development of the MAUSOM standard may resemble the development process of the similar eTOM standards as previously described. Models for governance of open standards [9] could be extended to cover all governance aspects for such system-of-systems. Additionally, recently a new ISO standardization effort on terminology related to automation of maritime autonomous surface ships [12] has been initiated.

In its evolution path towards widescale adoption, the MAUSOM should reflect the interests of the stakeholders, including both ships owners, operators, certification agencies and solution providers. This implies that the MAUSOM must strike the right balance for the level of granularity in defining its components since a too high level of granularity means a potential lock-in into specific modules, whereas a too low level of granularity means additional overhead in design and integration.

The introduction of the MAUSOM can be spurred through the involvement of early adopters, e.g. through the adoption by major, trend-setting, stakeholders in the maritime shipping arena. Initial field labs can test the viability and issues with deploying MAUSOM, both internally within organizations and across organizations. Its findings and results be broadly disseminated. The international shipping community (e.g. as organized within the IMO) may play a leading role in such an approach.

7. Conclusions and future work

This paper has introduced the Maritime Autonomous and Unmanned Shipping Operations Map (MAUSOM) as an overarching business process framework and operations map. Its main potential merits include that it provides a validated, complete and shared blueprint for (re-)designing the operational processes and its functions and tasks and for task (re-)allocation to either autonomous systems or to human operators. Moreover, it may reduce integration cost through improved system interoperability. The MAUSOM methodology has been described and motivated. The MAUSOM has been elaborated by functional decomposition into detailed levels of supporting functional capabilities.

Building upon the results as presented in the paper, the following topics for future work are identified:

- Elaborate the MAUSOM, e.g. with respect to:
 - the higher MAUSOM levels of detail for Level 2 Goals,
 - the MAUSOM Business and Customer Support layer and Suppliers & Partners domains,
 - the technical system for continuous health monitoring and incident management processes.

- Align, standardize and disseminate the MAUSOM to enable the realization of its benefits for the various stakeholders as addressed section 5.

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9. References

- [1] AAWA Remote and autonomous ships: the next step 2017 *Position paper*
- [2] Bradshaw J F, Hoffman R R, Woods D D and Johnson M 2013 The Seven Deadly Myths of "Autonomous Systems" *IEEE Intelligent Systems* Vol. 28/3
- [3] Breda van L, Janssen W H and Passenier P O 2001 Formal safety assessment (FSA) bulk carriers: Phase 1 – identification of critical functions. *Report TM-01-C020* (TNO, The Netherlands)
- [4] Broek van den J, Schraagen J M, Brake te G and Diggelen van J 2017 Approaching full autonomy in the maritime domain: paradigm choices and Human Factors challenges *Proc. of MTEC2017*
- [5] Bureau Veritas 2017 Guidelines for autonomous shipping *Guidance note NI 641 DT R00 E*
- [6] Diggelen van J, Janssen J and Tol van den W A 2016 Crew Design Tool *13th Int. Naval Eng. Conf.* (Bristol, UK)
- [7] EC 2017 Digital inland waterway area: Towards a digital inland waterway area and digital multimodal nodes doi: 10.2832/26584 (European Union)
- [8] EU European initiative to enable validation for highly automated safe and secure systems <https://www.enable-s3.eu/about-project>
- [9] Folmer, E 2012 BOMOS: Management and Development Model for Open Standards *Handbook of Research on E-Business Standards and Protocols* : (IGI Global) pp 102–28
- [10] IMO MSC 2018 Regulatory scoping exercise for the use of maritime autonomous surface ships (MASS) *MSC 99/5/5*
- [11] ITU 2004 Enhanced Telecom Operations Map (eTOM) - B2B integration: Using B2B inter-enterprise integration with the eTOM *ITU-T Recommendation M.3050.4*
- [12] ISO Ships and marine technology: Terminology related to automation of Maritime Autonomous Surface Ships (MASS) *ISO 23860*
- [13] Kaber D B 2018 A conceptual framework of autonomous and automated agents *Theoretical Issues in Ergonomics Science* Vol.19/4
- [14] Rødseth O J and Åsmund T A system architecture for an unmanned ship 2014 *Proc. of the 13th Int. Conf. on Computer and IT Applications in the Maritime Industries* (COMPIT 2014, Redworth, UK)
- [15] Rødseth O J, Kvamstad B, Porathe T and Burmeister H *Communication architecture for an unmanned merchant ship* 2013 *Proc. of IEEE Oceans* (Bergen, Norway)
- [16] Sheridan T B 2018 Comments on “Issues in Human–Automation Interaction Modeling: Presumptive Aspects of Frameworks of Types and Levels of Automation” by David B. Kaber *Journal of Cognitive Engineering and Decision Making* Vol. 12/1 pp 25–28
- [17] Sheridan, T B and Verplank, W L 1978 Human and Computer Control of Undersea Teleoperators. MIT Cambridge Massachusetts Man-Machine Systems Laboratory, Department of Mechanical Engineering.
- [18] Stanton N A, Salmon P M; Walker G H; Baber C and Jenkins D P 2005 *Human factors methods: a practical guide for engineering and design* (Ashgate Publishing Ltd)
- [19] Vagia M, Transeth A A and Fjerdingen S A 2015 A literature review on the levels of automation during the years. *Applied Ergonomics* 53 pp190-202
- [20] Wikipedia, Business process framework (eTOM)